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(NASA-CR-192134) PLANETARY ASTRONOMY RESEARCH Final Technical Report (California Inst. of Tech.) 9 p

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I. Introduction

This report constitutes the final technical report for the research in planetary astronomy at the California Institute of Technology supported under NASA grant NAGW-1710.

II. Work Accomplished under NASA grant NAGW-1710

Topics covered include:

A. Ring Systems in the Outer Solar System

Neptune

One of our major interests has been the study of the ring systems of Neptune and Uranus. We have observed these systems via stellar occultations at 2.2 microns. This technique utilizes the advantage that the planetary disk is substantially darker at 2.2 microns, as compared to the visible, to permit fainter stars to be used for occultation sources. In addition, the proximity of Neptune to the plane of the Milky Way results in many bright stars at 2.2 microns that can be used as occultation targets.

In the period prior to the Voyager Neptune encounter, much of our work was focused on observations of stellar occultation events by the Neptune system, to establish the structure of the apparent "ring arc" system. We observed 8 stellar occultations by the Neptune ring system in the period 1984-1988 to determine the properties of this system. The results of this survey have been reported in Nicholson, et al. (1990), which has the benefit of the hindsight of the Voyager flyby to help guide the interpretation of the occultation events.

The occultations suggest radial widths of arcs of 8-26 Km, and optical depths of 0.07-0.14. The comparison of the occultation data with the Voyager encounter imagery of the Neptune ring system shows that all of the confirmed occultations are associated with the outer Neptune ring 1989N1R. In addition the high signal-to-noise event observed only on the 200 inch telescope on 18 Apr 84 falls within the 6000 Km wide zone denoted 1989N4R.

Saturn

On 2 July 89, Saturn and its ring system occulted the star 28 Sgr. With its brightness at infrared wavelengths (K=1.5 mag, L'=1.3 mag) this represented a unique opportunity to probe the Saturn ring system. The high spatial resolution provided by the occultation (~20 km, set by the star's angular diameter) was comparable to that of the images returned in 1980/81 by the Voyager spacecraft.

ORIGINAL CONTAINS COLOR ILLUSTRATIONS

The goals of the observations were:

1) to derive optical depth profiles of the entire ring system at near infrared wavelengths. Combining these data with the Voyager data will lead to a refined estimate of the vertical thickness of

the ring particles.

2) to refine the precession rates for the ~10 non-axisymmetric features found in Saturn's rings by Voyager, which will lead to significant improvements in the determination of Saturn's higher order gravitational harmonics.

3) to detect the "aureole" caused by the forward scattering of starlight off the direct line of sight to the star, in order to assess the size distribution of ring particles in the size range 1-30 cm.

We utilized the near infrared camera on the 200 inch telescope (see below) to obtain imaging of the occultation at 4.0 microns through a 1.5% bandpass filter on a circular variable filter wheel. The wavelength was chosen to reduce the brightness of the rings to a minimum. Images were recorded at a frame rate of 10 frames/sec. Data were recorded nearly continuously over the 6 hours of the occultation event. To record the high volume of data (~1 Gbyte) required significant special software to be written for the 200 inch data system.

Because of the high volume of data involved, and the need to obtain accurate multiaperture photometry of 28 Sgr in each of the ~2×10^5 frames, special data handling routines have been developed to "flatten" each frame, to locate the star in each frame, and to do numerical photometry of the stellar flux in several apertures in each frame (for detection of the aureole).

B. Pluto - Charon Mutual Occultations

During 1988, we observed two Pluto-Charon mutual eclipse events, those of 30 Mar 88 and 3 May 88 UT, in the infrared on the 200 inch telescope to determine the spatial distribution of methane over the surface of these bodies. The observations were made at near infrared wavelengths using the broadband J, H, and K filters, as well as narrow band filters at 2.0um and 2.2um that were most sensitive to the rapidly changing (with wavelength) surface reflectivity of methane, and were intended to complement a mutual eclipse event observation of 1987.

One of the observed eclipses was a superior event (Pluto passing in front of Charon), and one was an inferior event. The observation of the inferior event of 30Mar88 from minimum flux to beyond last contact are shown in figure 1. These data provide information on the uniformity of the southern hemisphere surface coverage of Pluto, and show the expected color change as the water ice covered Charon moves out from in front of the methane covered Pluto.

C. Instrumentation

We introduced a near infrared Cassegrain camera on the 200 inch telescope, and this instrument has performed quite well. The infrared camera has 0.3" pixels and uses a 58x62

InSb array for a total field of view of roughly 18" on a side. We currently can work using the broadband J,H,K,and L'filters, and a narrowband 5 micron filter with bandwidth 0.1 micron and using a 1.8-2.6 micron, 1.3% bandpass Circular Variable Filter (CVF) or a 2.8-5.6 micron, 1.5% bandpass CVF. The measured image quality has been found, on nights of good optical seeing, to be less than 2 pixels, and so is limited by sampling. By using shift and add techniques and fairly short integrations (~5 sec, see Graham, et al. 1990), we have been able to achieve spatial resolutions of <0.5" (FWHM).

The array is operated at 30K, and has a dark current less than 90 electrons/sec. At all wavelengths, including in the 1.3% bandpass filter of the 1.8um-2.6um CVF, the sky background is larger than the dark current. The read noise was originally ~450 e. More recently, using the technique described by Fowler and Gatley (1990), we have achieved a read noise of ~100 e. At all broadband wavelengths, the sky background is such that the camera achieves background limited performance in reasonable integration times. In particular, at 2.2 microns, we now achieve background limited performance in ~ 1 second of integration.

Our measured performance at 2.2 microns for a total of 2 minutes of observation (one minute on object and one minute on sky) is a 1 sigma noise of 21.2mag/pixel, or for 6 pixels for a stellar image, 20.3 mag, 1 sigma. The equivalent numbers at 1.6um are 21.5 mag/pixel and 20.6 mag for a star in 2 min. At 1.2um, with 4 minutes total integration (2 minutes object, 2 minutes sky) the numbers are 22.7 mag/pixel, 21.6 mag for a star.

D. Planetary Imaging With the Palomar Cassegrain Near Infrared Camera

The versatility of the Palomar Cassegrain Near Infrared Camera is illustrated in figures 2 and 3, images of Jupiter at a variety of wavelengths. Figure 2 shows an image of Jupiter obtained at 5 microns. This image was made as a mosaic from 21 frames taken with the infrared camera on the 200 inch telescope. The image is color coded for intensity. The individual frames in the mosaic represent 1 second of integration. Each of these frames is in fact a coaddition of 32 individual 35 millisecond exposures. The short exposure time is necessitated by the high background at this wavelength. The individual frames were offset by 15". Note the bands at 5 um, and the apparently periodic holes in the clouds near the south pole of Jupiter.

In addition to imaging Jupiter at 5 microns, we have imaged the disk of Jupiter in the broadband K filter and in the depth of the strong methane band at 2.3 microns (figure 3). The images of the disk of Jupiter at 2.3 microns, in addition to showing features seen at other bands, shows bright polar caps not seen at other wavelengths. Because of the exceedingly strong absorption of methane at this wavelength, the most likely explanation of the bright polar caps is a layer of aerosols that dominates the scattering at high altitudes in the Jovian atmosphere.

Using the fact that Jupiter is exceedingly dark in the K band, thereby making the faint Jovian ring easily visible, we obtained 150 frames of the ring and its two associated satellites, Metis and Adrastea on a single night. Analysis of these images has lead to refined orbits for both of these satellites (Nicholson and Matthews, 1991), and a demonstration of the usefulness of the infrared camera for astrometric work. These images clearly show the Jovian ring, discovered by Voyager in 1979, and possibly the fainter "halo" which extends inward from the main ring. An image of the ring is shown in figure 4.

In April and again in July of 1989, we attempted to search for ring arcs and sheparding satellites in the Neptune system at 2.2 microns prior to the Voyager encounter. In April, Neptune was at its highest apparent Galactic latitude of the year, and the density of background stars was minimized. Unfortunately the largest of the new Neptune satellites 1989N1 was not immediately found over the five nights of observations. With the discovery by Voyager of this satellite, we have re-examined these images to carefully search for this satellite. Figure 5 shows a stack of several coadded frames of Neptune, from July 89. There is agreement to within 0.3" between the position of 1989N1 and the object noted in the figure.

As an outgrowth of searching for satellites of Neptune, we obtained images of Neptune at 2.2 microns with sub-arc second seeing. These images revealed the presence of a stationary bright region on or near the northern limb and several bright spots in the southern hemisphere that rotate with the planet. The altitude at which the 2.2 micron light is reflected is quite high, so it is surprising that any "weather" related features are seen. This suggests rather substantial vertical extent of convective motions in the Neptunian atmosphere.

We have imaged the Uranus system to study the structure of the ring system, using the capability to image in narrow bands throughout the 2.2 micron window to search for the faint broad, diffuse inner ring 1986U2R that was detected in a single Voyager image. An image obtained in 1989 (figure 6) suggests the presence of this faint inner ring.

E) Solar System Survey

During the second Palomar Sky Survey, we have provided support to have people scan the plates to find new asteroids and comets. This work has successfully found several such objects. Objects such as 1987 OA, PA, and QA, 1989 DA, and Comets Helin (1987w) and Mueller (1987a1) were found in this search of the POSS II plates.

References

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Graham, J.R., Carico, D.P., Matthews, K., Neugebauer, G., Soifer, B.T. and Wilson, T.D. 1990, Ap.J. 354, L5

Nicholson, P. Cooke, M., Matthews, K., Elias, J.H. and Gilmore, G. 1990, Icarus

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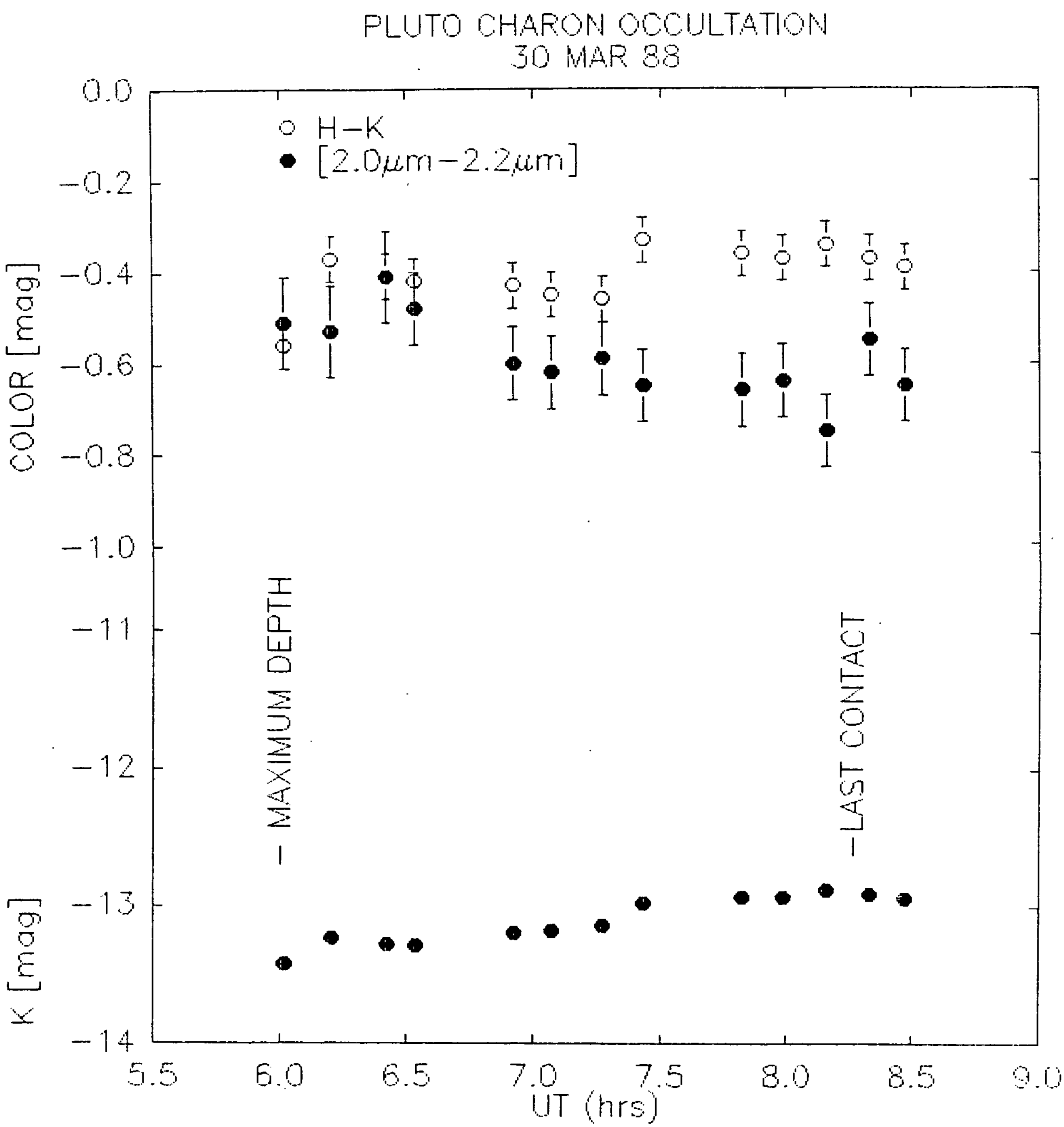

Figure 1 The observed light curve of Pluto-Charon during the mutual event of 30 Mar 88. In this inferior event, which was observable from Palomar only from maximum depth onward, as Pluto emerges from behind Charon, the [H-K] and [2.0um - 2.2um] colors change as expected with the increasing contribtion to the total light of the methane covered Pluto.

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COLOR PHOTOGRAPH

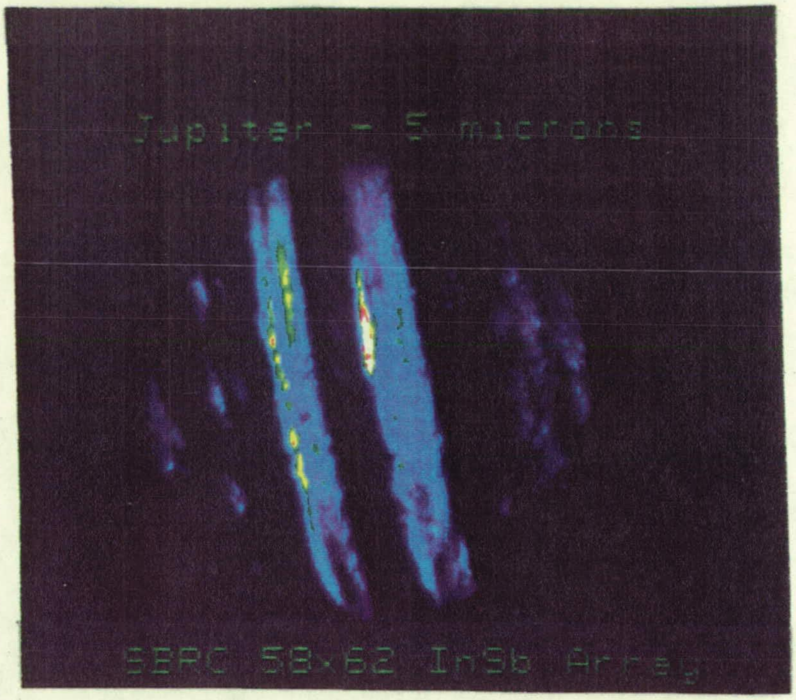

Figure 2 A false color image of Jupiter at narrowband 5 microns (black faintest, blue to white increasingly bright) obtained with the Near Infrared Cassegrain camera on the 200 inch telescope. The image is a mosaic of 21 frames, each frame consists of 32 coadded pictures of 35 msec integration. Each pixel is 0.3", with resolution in this image less than 1". The short integration is required to avoid saturation of the pixels in the high background at 5 microns. The bright equatorial bands are cleary visible, as are several regions at higher latitudes.

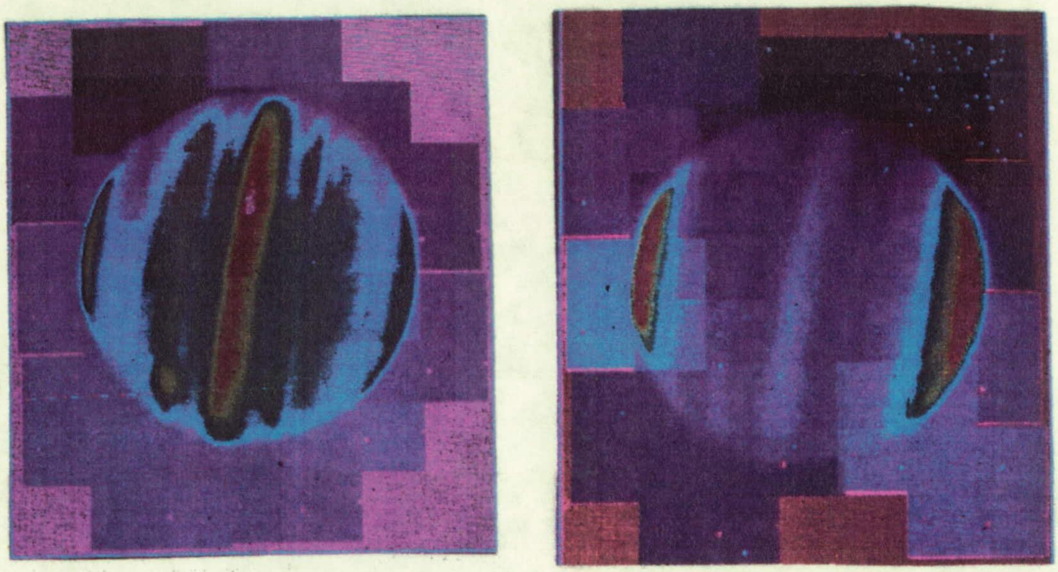

Figure 3 False color images of Jupiter in the broad band K (2.2 micron) filter (left) and in the strongest part of the 2.3 micron methane feature (right). Each image is a mosaic of 15 frames. The central band and polar caps are seen in the K image, while the brightest regions in the 2.3 micron are the polar caps.

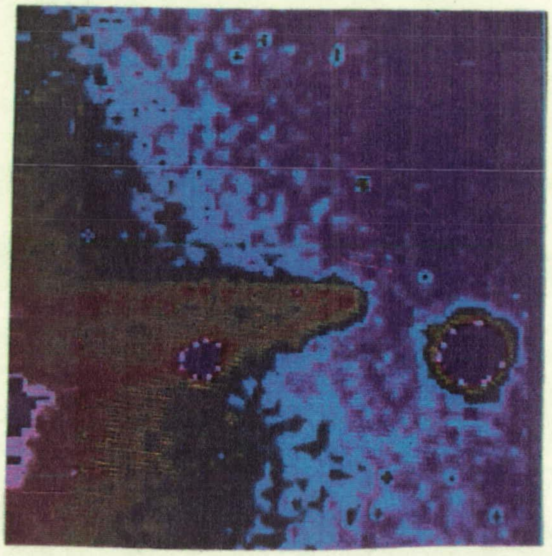

Figure 4 False color image of the Jupiter ring system in the K band. White/red is brightest, and blue/purple is faintest. While the frame is completely off the disk of the planet, the strong scattered light from Jupiter is still the dominant light source in the field. Since Jupiter is darkest by far at this wavelength, this illustrates the need to use this filter to find faint features close to planetary disks. In the image are Amalthea (brighter point source), and Metis, one of the sheparding satellites of the ring.

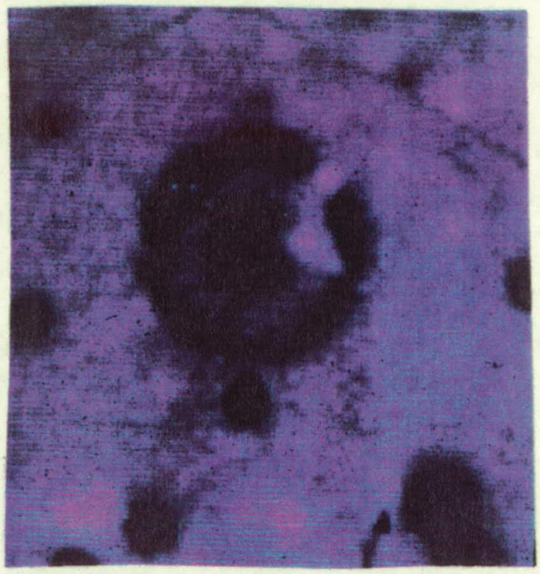

Figure 6 A K band image of Uranus obtained in April 1989 with the Near infrared Cassegrain camera. The white spots in the frame are locations where stars appeared in the sky frame. The ring is quite prominant, and there is a suggestion of the inner ring 1986U2R seen in 1 frame by Voyager.

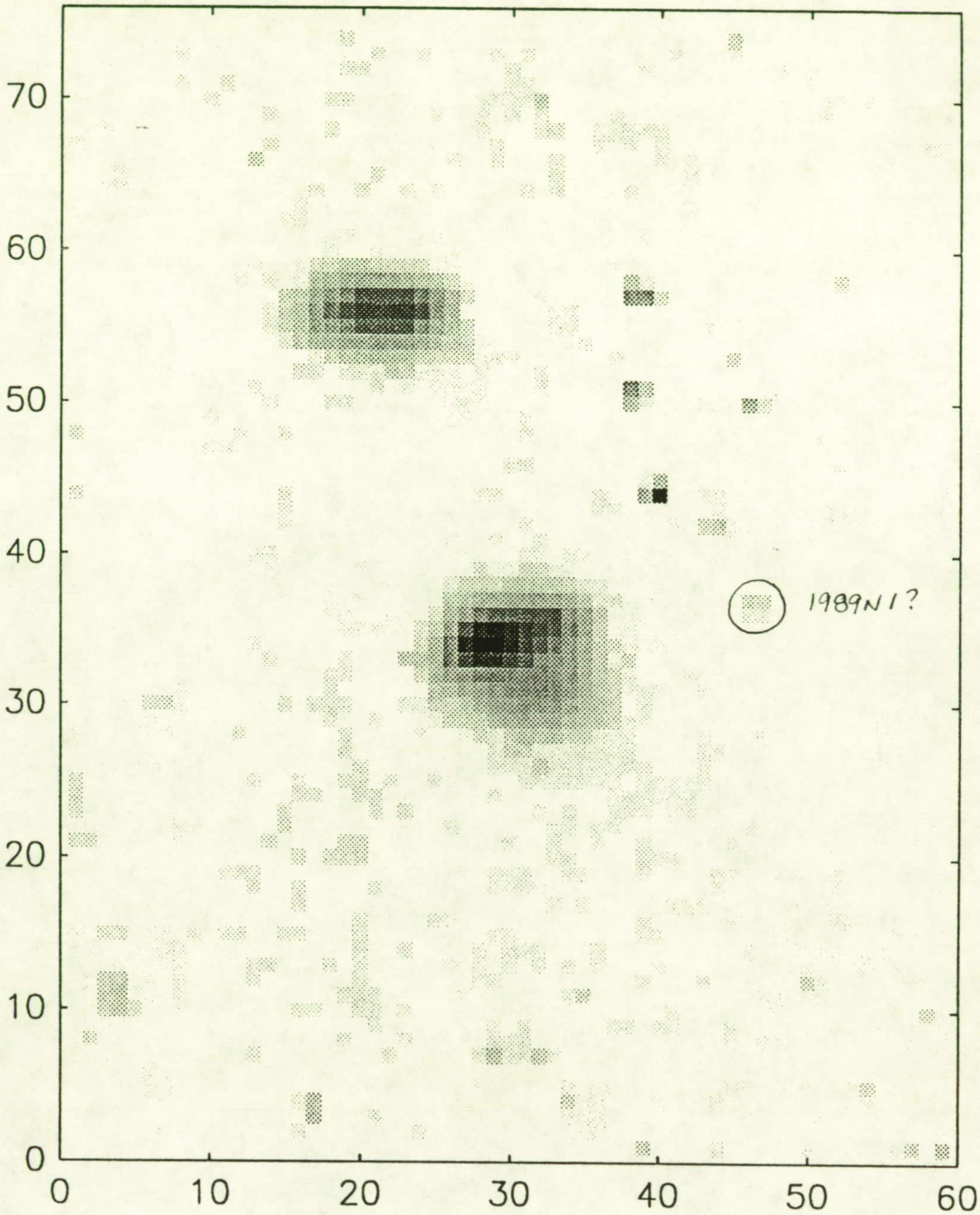

Figure 5. A stack of five 1 minute exposures of Neptune obtained in the K filter over a half hour period in July 1989. The images were coadded with respect to Neptune, so the bright star is blurred in the direction of Neptune's motion. The gray scale image is clipped at 1 sigma of the median noise in the frame, so that the features not associated with the well known defects in the array should be real. The object noted lies within 1 pixel (0.3") of the position of the Neptune satellite 1989N1, and so is a plausible detection of this satellite. Note also the several features in the Neptune image, indicating bright spots on the disk.